Mill, Hugh Robert, D.Sc.
Muir, Thomas, M.A.
Oliver, John Ryder, Major-General (late R.A.).
Payne, Joseph Frank, M.D.
Perkin, Arthur George.
Rambaut, Professor Arthur A., M.A.
Russell, James Samuel Risien, M.D.
Salomons, Sir David, M.A.
Saunders, Edward.
Schlich, Professor William, C.I.E.
Sell, William James, M.A.
Sidgreaves, Rev. Walter, S.J.
Smith, James Lorrain, M.D.
Smith, Professor William Robert, M.D.
Smithells, Professor Arthur, B.Sc.
Spencer, Professor W. Baldwin, B.A.
Swinburne, James.
Swinton, Alan Archibald Campbell, Assoc. M.Inst.C.E.
Symington, Johnson, M.D.
Tatham, John F. W., F.R.C.P.
Thomas, Michael Rogers Oldfield, F.Z.S.
Ulrich, Professor George Henry Frederic, F.G.S.
Walker, James, M.A.
Walker, Professor James, D.Sc.
Waterhouse, James, Colonel.
Watkin, Colonel, R.A.
Watson, William, B.Sc.
Watts, Philip.
Whetham, William C. D., M.A.
White, William Hale, M.D.
Wilson, Charles T. R., M.A.
Woodhead, Professor German Sims, M.D.
Woodward, Arthur Smith, F.G.S.
Wright, Professor Edward Perceval, M.A.

The following Papers were read:—

I. "An Experimental Inquiry into Scurvy." By F. G. JACKSON and VAUGHAN HARLEY. Communicated by LORD LISTER, P.R.S.

II. "The Velocity of the Ions produced in Gases by Röntgen Rays." By Professor J. ZELENY. Communicated by Professor J. J. THOMSON, F.R.S.

III. "Mathematical Contributions to the Theory of Evolution. VIII.—On the Correlation of Characters not Quantitatively Measurable." By Professor KARL PEARSON, F.R.S.

"Researches on Modern Explosives. Second Communication."

By W. MACNAB, F.I.C., and E. RISTORI, Associate M. Inst., C.E., F.R.A.S. Communicated by Professor RAMSAY, F.R.S.

Received January 29,—Read February 1, 1900.

In our communication published in the 'Proceedings of the Royal Society,' vol. 56 (in which we gave results of the determination of the calories evolved and analysis of the products of combustion of various

explosives), reference was made to certain experiments we had then begun for the purpose of determining the actual maximum temperature reached during explosion. We have now made a long series of experiments in this direction, and propose to communicate some of the results so far obtained, although the research is not yet complete.

Some experiments have already been made by others for the purpose of determining the temperature during explosion by placing strips of metal of different melting point in a closed bomb and observing the result after firing. Noble and Abel in their well-known communication on explosives found in this way that the temperature produced by the explosion of black gunpowder was slightly above the melting point of platinum.

There have been also several communications, on the same subject, made by others, who have deduced the temperature during explosion from theoretical considerations, but these calculations involved assumptions which as yet do not rest on an experimental basis. It appeared to us desirable, therefore, to endeavour to determine experimentally, and with greater accuracy than has hitherto been done, the actual temperature developed when an explosive is fired in a closed vessel.

The practical solution of this problem is, however, beset by several difficulties; amongst others, the intensity of the temperature, the extreme shortness of duration of the maximum temperature, and the necessity of conducting the explosive reactions in a closed vessel.

We were led to try a modification of the pyrometric method developed by Sir W. C. Roberts-Austen, by observing that a thin platinum wire used for firing the explosive in the vessel by electricity was often melted by the heat produced by the explosion, while thicker platinum wires, which served to support the capsule containing the explosive, were unaffected.

This showed that the temperature reached was above the melting point of platinum, and also that the duration of the maximum temperature was very short. In the case of the thin wire, the small mass of the metal allows the heat to penetrate it with sufficient rapidity to raise it to the melting point before the period of maximum temperature is past, while with the thick wire the time does not suffice for the larger mass to be heated to the same extent.

These considerations led us to argue that if rhodium-platinum couples of wires of different diameters, sufficiently thick not to be melted during explosion, were used in a bomb, the deflections of the galvanometer indicated would vary inversely with the sizes of the wires forming the couples; that in this way we might get data which would enable us to calculate the deflection of an infinitely thin couple which could be capable of taking up the heat in an infinitely short time, and that this deflection, expressed in degrees, would represent the actual maximum temperature reached. We also expected

that the indication of the galvanometer would show the rapidity with which the temperature rose at the moment of the explosion, as well as the rate at which the cooling took place.

Through the kindness of Sir W. C. Roberts-Austen we were enabled to make some preliminary experiments in his laboratory, connecting the wires from a couple in our bomb with the galvanometer in his photographic-recording apparatus. The results of these experiments were so encouraging that a similar photographic-recording apparatus was procured, only introducing such slight modifications as were required to make it more suitable for our purpose.

We also had a special lid made for the calorimetric bomb previously described in our former communication, this lid being similar to the other, with the exception of two insulated conical pins, one made of pure platinum and the other of platinum alloyed with 10 per cent. of rhodium. These pins were used in the inside of the lid as points of attachment for the thermo-couple, their ends outside the lid being connected with the galvanometer. The couples were made of platinum and rhodium-platinum wires in contact. Several couples of different thicknesses were prepared for us by Johnson and Matthey, fusing the ends of the platinum and rhodium-platinum wires together and then drawing the junction through a die until it had the same diameter as the rest of the wire.

As we shall have to refer to these couples by number in future, we give in Table I the diameters and areas, and the number by which we distinguish each couple. As will be seen, ten different couples were made, the diameters varying from 0·044 to 0·01 of 1 inch :—

Table I.

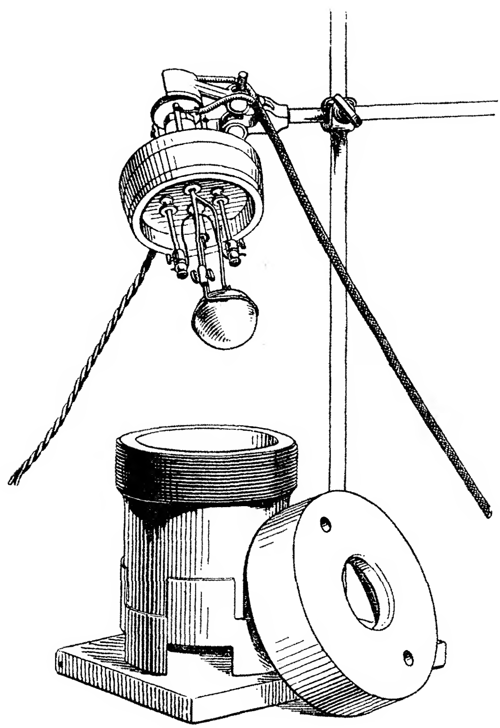
Couple No.	Diameter in inches.	Area in sq. inches.
1	0·044	0·00152
2	0·040	0·00125
3	0·035	0·00099
4	0·028	0·00061
5	0·026	0·00053
6	0·022	0·00037
7	0·018	0·00025
8	0·015	0·00017
9	0·012	0·00011
10	0·010	0·00008

Fig. 1 shows the explosive bomb with the lid separate, and the arrangement of connections which are made through the lid are clearly seen. Three insulated pins pass through the lid; two of them, as above indicated, are those which connect with the thermo-couple, the other one is used as one of the terminals for the firing wire, the

other terminal being attached to the body of the bomb outside. Thus there are two electric circuits absolutely insulated from each other.

The position of the cup which contains the explosive can be seen in the figure (fig. 1), and the position of the couple in respect to the cup

FIG. 1.



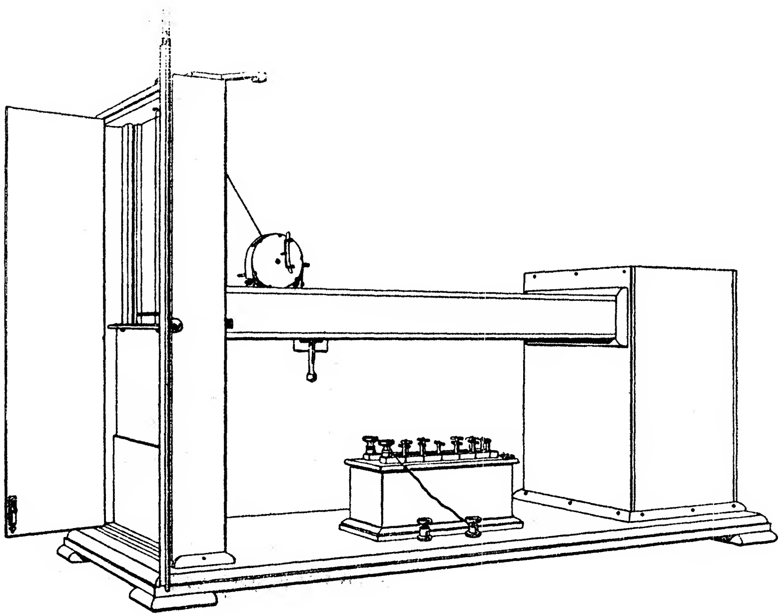
ied in a way that will be explained later on. The con-
n the firing wire were led to an electric battery, which is set in action when it is required to ignite the explosive.

The connections from the thermo-couple are led to the galvanometer, which is inside the recording apparatus shown in fig. 2. The general details of the apparatus are well known, and have been described by Sir W. C. Roberts-Austen.

Lime-light is used to throw a spot of light on the mirror of the galvanometer, from which it is thrown on to a photographic plate through a horizontal slit, equal in length to the breadth of the plate. This photographic plate is held in a weighted frame, which falls past the slit with a rate of descent uniformly regulated by clock-work, con-

trolled by adjustable vanes. The rate of descent of the plate in the experiments was one inch in $2\frac{1}{2}$ seconds, or equal to four-tenths of an inch for every second of time.

Fig. 2.



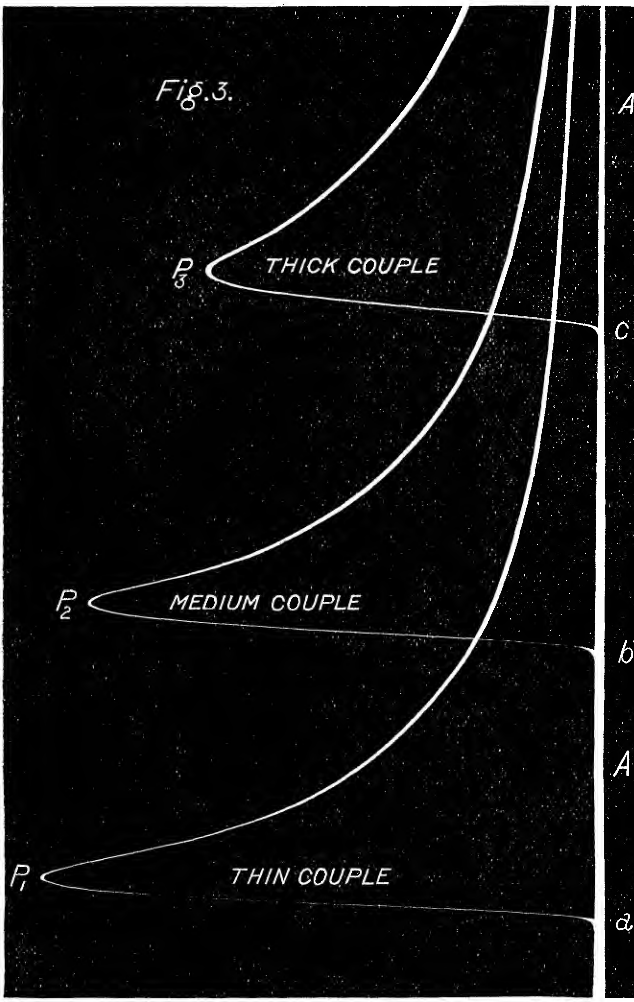
In using the apparatus, a datum line is first traced, and this is done by letting the plate fall with the galvanometer at rest, the circuit being closed, when the spot of light traces a continuous vertical line at one edge of the plate. The plate is then brought back to its original position and re-started on its descent. After it has fallen a short distance, in order to make sure it has acquired a steady rate of motion, the explosive is fired and the thermo-couple in the bomb is in consequence heated, and the current generated deflects the mirror of the galvanometer, and therefore the spot of light, horizontally and proportionately to the temperature attained by the couple; and then, as cooling sets in, the original position of the spot of light is gradually resumed.

The result is recorded as a curve, which shows the combined movements of the spot of light and of the photographic plate.

Fig. 3 shows one of the plates on which three records were successively taken. In these three separate experiments, couples of different thicknesses, but with the same charge and kind of explosive, were used.

AA is the datum line; the point of departure *a* of the spot of light from it shows when the first charge was fired; the spot of light, owing to the deflection of the galvanometer, travelled rapidly to the

Fig. 3.



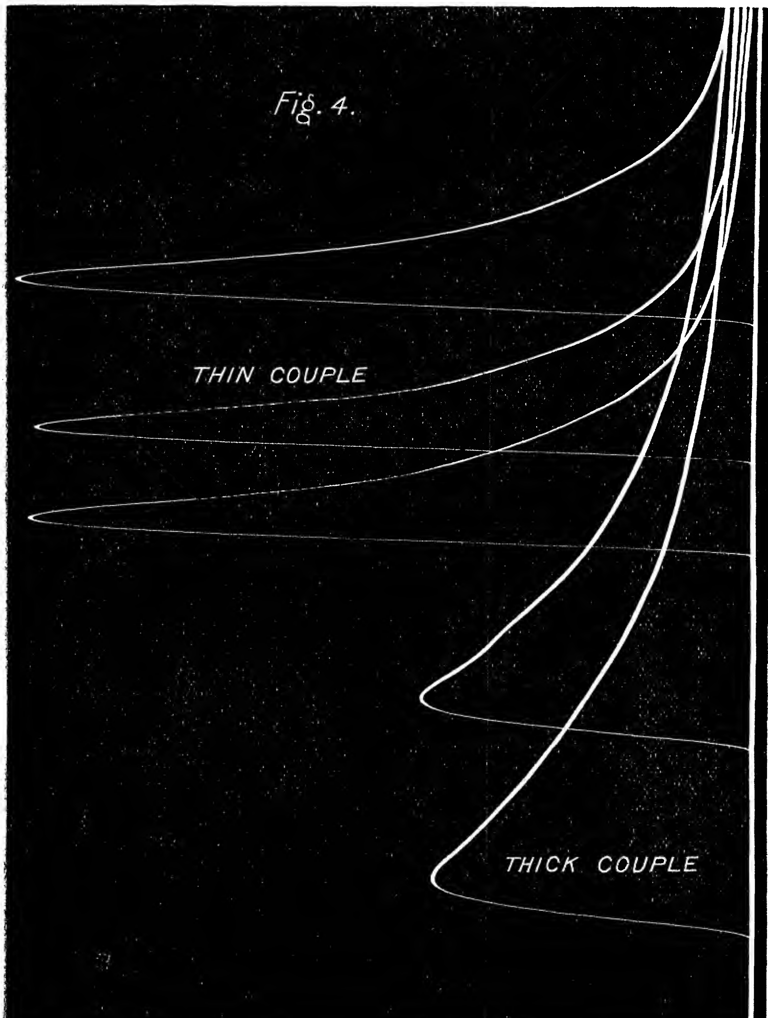
left, until the maximum point P_1 was reached, then more slowly returned, as cooling set in, towards its normal position. *b*, *c*, P_2, P_3, are the corresponding points in the other two experiments.

The maximum deflections, as shown by P_1, P_2, P_3, are seen to be in inverse order to the thickness of the couples used, the greatest deflection being obtained with the thinnest couple.

It is also noticeable that the thinner the couple the sooner is the maximum point reached, *i.e.*, the steeper is the curve and the sharper its point, while with a thicker couple the point is more rounded, and the maximum more slowly reached.

Fig. 4 shows photographs of five results, two with a thick, and three with a very thin couple.

FIG. 4.



Many difficulties were encountered in carrying out these researches in order to secure reasonable accuracy in the work. Several hundred

experiments have been made on the lines above indicated, but a large number of the results have had to be discarded.

To begin with, one point which had to be studied was whether the size of the grain of the explosive would make any difference in the results; but after numerous experiments we have come to the conclusion that, within reasonable limits, the size of the grain exercises no influence under the conditions of these experiments.

In all the experiments about to be described, the explosives used were all gelatinised preparations of gun-cotton alone, or mixed with nitro-glycerine, all in the form of small grains, and the charges were fired in the bomb full of air.

A difficulty observed was that the deflections of the galvanometer were different, everything else being equal, when the position of the couples varied in relation to the position of the explosive. It became necessary, therefore, to carry out a series of experiments in order to determine which position of the couple gave greatest and most uniform results.

The following Table II gives the results of the experiments made to find the hottest place in the bomb. The same charge of the same explosive and the same couple were used in all the experiments, the only difference being that the position of the couple in relation to the explosive which was held in a platinum capsule. Three experiments were made in each position.

Table II.

Couple No. 5.

	Deflection of light in mm.	Mean.
Position of couple bent into capsule in centre of charge	118, 131, 130	126·3
Couple 1″ above explosion	159, 156, 149	154·6
„ 2″ „	156, 163, 153	157·5
„ 3″ „	168, 165, 163	165·5
„ $3\frac{1}{4}$″ „ (furthest practicable)	160·5, 168·5, 155·4	161·4

These results are shown graphically in Diagram 1, where the vertical distance represents the deflection of the galvanometer, and the horizontal the position of the junction of the couple in relation to the charge. The deflection is least when the junction is embedded in the charge, and greatest when about 3 inches above it.

As will be seen from the diagram, there is very little variation in the results between $2\frac{1}{2}$ inches and $3\frac{1}{4}$ inches (the maximum distance allowed by the size of the bomb), and as the actual maximum was shown at 3 inches, we have in all future experiments placed the thermo-couple at 3 inches above the surface of the charge.

Another point which we had to consider was the different deflection caused by the firing of different quantities of the same explosive in the same bomb.

DIAGRAM 1.

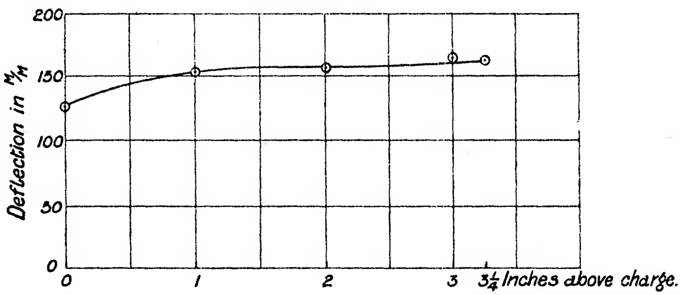
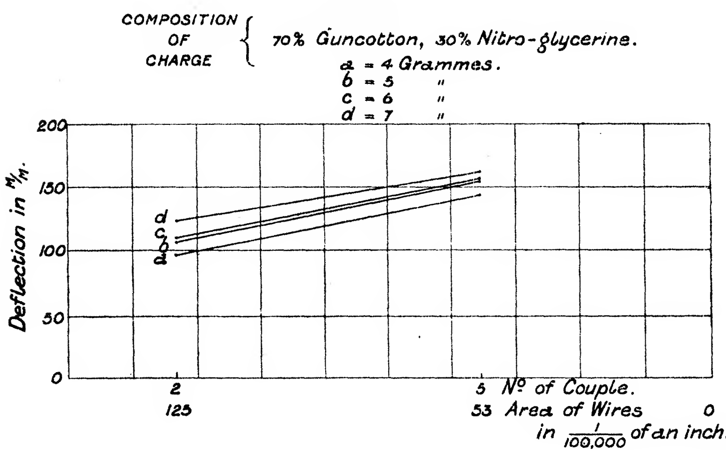


Diagram 2 shows the result of firing 4, 5, 6, and 7 grammes of the same explosive in the same volume with couples 2 and 5.

DIAGRAM 2.



The points of deflection have been connected by a straight line simply for the purpose of showing the general parallelism of these observations.

With charges of less than 4 grammes the results were very irregular, and we have not fired charges larger than 7 grammes, the bomb not being constructed to withstand high pressures.

Having thus ascertained the conditions of working which gave fairly concordant results, a series of experiments was made with couples of different diameters, and, by means of introducing some suitable resistance into the circuit of the galvanometer, it was arranged that the

deflection when the thinnest wire was used should be about the maximum that the photographic plate could record.

The explosive used for this series of experiments was Ardeer ballistite, composed of 70 per cent. gun-cotton and 30 per cent. nitroglycerine, and was in the form of thin square flakes. In each case three experiments were made, and the results are shown in Table III.

Table III.

Charge, 4 grammes Ardeer Ballistite, 70 per cent. Gun-cotton, 30 per cent. Nitro-glycerine.

No. of couple.	Deflection in mm.			Mean.	Maximum.
1	85,	81·5,	83·5	83	85
2	102,	90·5,	98·5	97	102
3	109,	115·5,		112·5	115·5
4	131,	128·5,	138·5	132·5	138·5
5	149,	149,	147	148	149
6	152·5,	158·5,	151	154	158·5
7	161,	170,	166	165·5	170
8	185·5,*	192		189	192

* After the first experiment, the wire was partially fused, but not broken.

It will be seen that the results are fairly uniform, the average variation from the maximum to mean being only between 2 and $2\frac{1}{2}$ per cent.

In the case of couple No. 8, which is only 0·015 inch in diameter, we found that after the first experiment it was partially fused but not broken, thus showing that we had reached the practical limit of fineness of wire for this particular explosive.

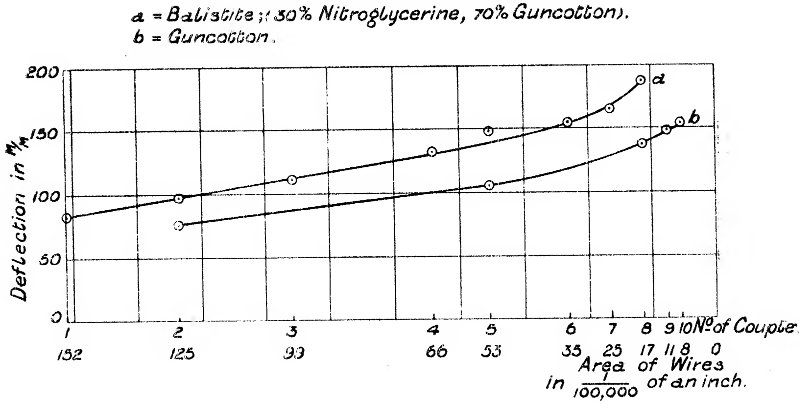
The character of the increase of the deflection in inverse proportion to the diameter of the couple is clearly shown in Diagram 3, where two similar curves are shown for two different explosives.

The curve A shows the results given in Table III, and the curve B the results of a similar series of experiments made with gun-cotton fired with couples 2, 5, 8, 9, and 10.

In the case of gun-cotton, the temperature being so much lower, as clearly shown in the diagram, we have been able to use thinner couples, and there was no fusion up to No. 10, which is 0·01 inch diameter, but a thinner couple (0·005 inch) was fused. The curves have been drawn as nearly as possible following the actual measurements, which are indicated by dots surrounded by circles; as it will be seen, the curves are very regular, and it is particularly noticeable that the curves of the two explosives are very similar in character.

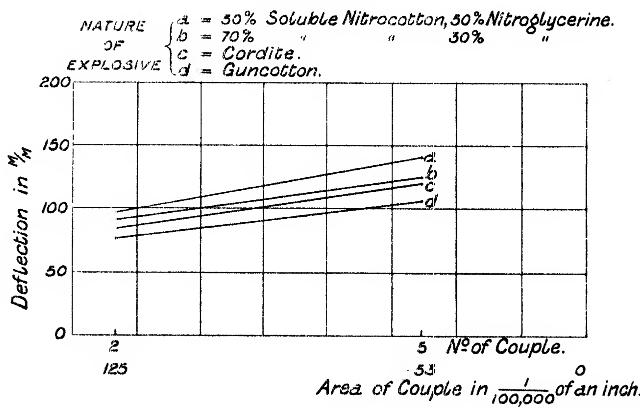
In order to get comparative data for several explosives, we made

DIAGRAM 3.



another series of experiments, the results of which are indicated in Diagram 4.

DIAGRAM 4.



The vertical lines indicate, as before, the maximum deflection of the galvanometer obtained with charges of 4 grammes with couples 2 and 5 for the following explosives: Gun-cotton, cordite, ballistite of 70 per cent. soluble nitro-cotton, and 30 per cent. nitro-glycerine, and ballistite containing 50 per cent. soluble nitro-cotton and 50 per cent. nitro-glycerine.

In the same way as in Diagram 2, each of the points corresponding have been connected by straight lines to show the parallelism of the observations.

It will be seen from the diagram that the larger the proportion of nitro-glycerine in the ballistite the higher is the temperature during

explosion; but, on the other hand, cordite, although it contains as much as 58 per cent. nitro-glycerine, owing to the fact that it contains also vaseline, gives a temperature lower than that of ballistite containing only 30 per cent. nitro-glycerine and no vaseline. Of course, the minimum deflection is the one due to gun-cotton, which contains no nitro-glycerine.

Similar experiments have also been repeated with other explosives and with different charges, and, in every case, the same comparative results have been obtained.

The above refers only to a part of the experiments which have been carried out so far. Another series is now in progress for determining the other necessary elements which will be required before we can accurately express the value of these deflections of the galvanometer in degrees of temperature. One important element which comes into play is the inertia of the galvanometer itself in connection with the shortness of the time during which the maximum temperature exists, and there are also other points which are being investigated, and these will form the subject of a further communication.

We have, however, thought it advisable not to delay communicating the above results, as already the described method shows the possibility first of all of obtaining approximately an idea of the temperature during explosion, and, secondly, it shows a clear way by which the comparative temperatures for various explosives can be determined. These, taken in connection with the results shown in our former communication, will serve, we hope, to give a better knowledge of the different modern explosives which are now commonly used.

"The Spectrum of α Aquilæ." By SIR NORMAN LOCKYER, K.C.B., F.R.S., and A. FOWLER. Received January 18,—Read February 8, 1900.

[PLATE 1.]

The study of enhanced lines throws considerable light on the spectrum of α Aquilæ, the peculiarities of which were first described by Professor Pickering* and Dr. Scheiner† in 1889. In this spectrum the lines of hydrogen are strong and broad, but the additional lines, instead of being faint and sharp as in most other stars of this class, are faint and diffuse. Dr. Scheiner stated that these apparent bands were identical with the most conspicuous groups of lines in the solar spectrum, and further that this appearance of the spectrum can be

* Third Annual Rep. Henry Draper Memorial, p. 5.

† 'Ast. Nach.,' 2924.

FIG. 1.

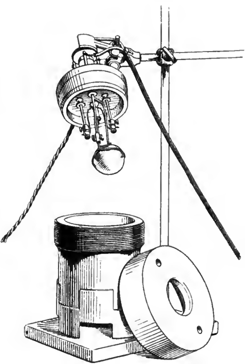


Fig. 2.

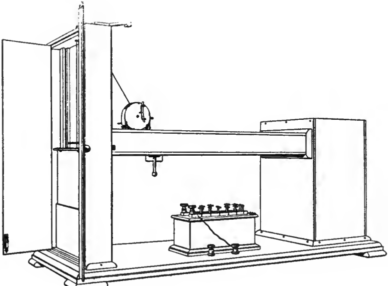


Fig. 3.

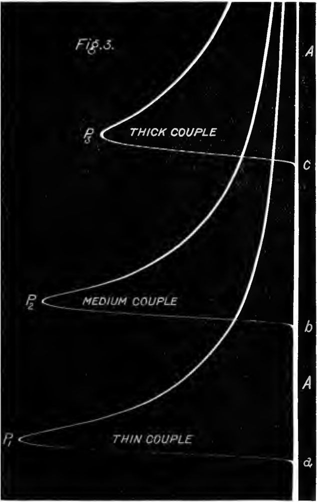


FIG. 4.